NEWGAIN PROJECT AT GANIL: CONSTRUCTION OF THE NEW HEAVY ION INJECTOR FOR SPIRAL2*

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Abstract

The NEWGAIN (NEW GAnil INjector) project is now in the construction phase at GANIL. It aims to install a second injector for the SPIRAL2 facility. It is designed to accelerate heavy ions with a mass-to-charge ratio (A/q) of up to 7. With this upgrade, SPIRAL2 will provide high-intensity beams, from protons to uranium, strengthening GANIL international competitiveness, both in fundamental sciences and related applications. The paper will provide an update on the progress of the construction phase and the main milestones achieved and to come. The layout and the main technical components of the new injector, based on 2 ECR ion sources (one of them existing), two Low Energy Beam Transport (LEBT) line, one RFQ and a Medium Energy Beam Transport (MEBT) line to transport the beam into the present MEBT connected to the SPIRAL2 LINAC are presented.

INTRODUCTION

The NEWGAIN project aims to build a second injector designed for A/q = 3 to 7 ions, to produce and accelerate very intense heavy ion beams using a new RFQ (RFQ2) up to uranium, far exceeding the performance of the existing injector. Thus, a new superconducting source will be developed to complement the existing sources and achieve high-intensity uranium beams.

Thanks to this improvement, the Système de Production d'Ions Radioactifs en Ligne de 2ème génération (SPIRAL2) LINAC [1] will deliver, within the limits of its operating energy, the most intense beams in the world (Table 1) on a wide variety of ions ranging from protons to uranium, and will strengthen GANIL's international competitiveness, both in fundamental sciences and in associated applications.

The project is organized within a large technical collaboration framework, composed of the following French accelerator laboratories of CEA/DRF/IRFU and CNRS/IN2P3: GANIL, IRFU/DACM and DIS, LPSC, LPCCaen, IPHC, LP2iB, IJCLab. These different partners have already collaborated in different projects with GANIL, the latest example to date being the construction of the SPIRAL2 facility. The NEWGAIN project is coordinated by GANIL.

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Table 1: Ion Beam Intensities SPIRAL2 vs NEWGAIN

Ions	Intensity [pµA]		
	SPIRAL2	**NEWGAIN**	
	Phoenix V3 A/Q≤3	Phoenix V3 A/Q≤6	Superconducting Ion Source A/Q≤7
18O	80*	-	375
19F	>15	>40	>40
36Ar	16*	70	45
40Ar	3.6	70	45
36S	2.3	-	-
40Ca	2.9*	10	20
48Ca	1.2	10	20
58Ni	1.1*	4	8
84Kr	0.1	10	20
139Xe	0.001	7	>10
238U	<<0.001	0.1	10

*Measured, Foreseen

GENERAL LAYOUT

This second injector is designed to be fully compatible with the existing facility (Fig. 1) and to further enhance its 'multi-user' capabilities. It is composed of the following (Fig. 2):

- A high-performance superconducting ion source (the Source 1/7) called ASTERICS [2]
- Low energy beam transport lines connecting the ion sources (superconducting ion source and existing room temperature ion source) to the RFQ (LBE3). The mass separation at the exit of the ion sources can be tuned up to 150, depending on the ion choices and the experiment needs,
- A RFQ that will accelerate heavy ions with minimal beam losses up to the injection energy for the superconducting LINAC (RFQ2),

- A medium energy beam transport to the LINAC (LME2), giving also the possibility to send the beam into an experimental area (to be built) in the future.

The injector will be installed in an existing cave built 15 years ago in the SPIRAL2 building. The view of the injector inside the existing facility is shown on Fig. 3.

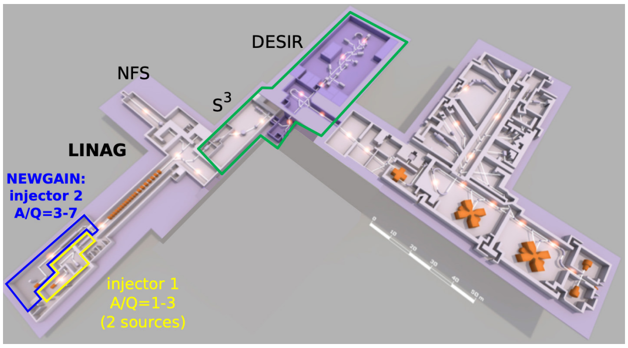

Figure 1: General layout of the NEWGAIN injector.

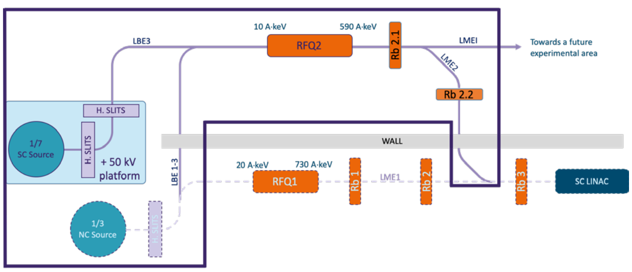

Figure 2: NEWGAIN principle layout (in dotted lines are the existing elements of SPIRAL2).

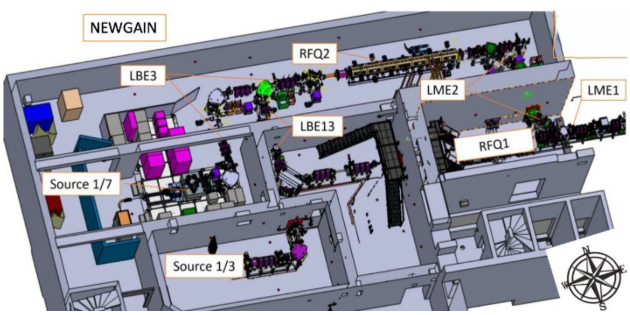

Figure 3: General 3D layout of the NEWGAIN injector inserted in the SPIRAL2 building (preliminary design).

The main injector parameters and reference beams considered for the design are listed in Table 2. The beam coming from the existing source will be limited to A/q=6, since the current maximum source extraction voltage is fixed at 60 kV.

PROJECT STATUS

Since May 2023, the project has entered into the construction phase, except for the superconducting ASTERICS source and its platform which are still in the detailed design phase. The project is divided into two phases. The first phase will involve both GANIL and LPSC. At GANIL, it will include the installation of the injector connecting the existing Phoenix V3 source to SPIRAL2 LINAC via the new RFQ2. And at LPSC (Grenoble, France), where the ASTERICS source will be installed for the production of the uranium beam commissioning.

Table 2: NEWGAIN Main Parameters

Main Frequency	**88.0525**		**MHz**
LEBT Input energy	10		keV/A
MEBT Input energy	0.590		MeV/A
HEBT Input energy for A/q=7	7		MeV/A
Reference beams	$^{48}\mathbf{Ca}^{11+}$	$^{238}\mathbf{U}^{34+}$	
Normalized RMS emittance	0.2	0.15	π.mm.mrad
Beam intensity	220	340	μA
LEBT beam power	10	24	W
MEBT beam power	0.54	1.4	kW
HEBT beam power	6.9	16.7	kW

Phase 2 will start after the validation of the ASTERICS source. It will allow the integration of the source into GANIL NEWGAIN line to transport uranium beams to the experimental room of GANIL. As the period of tests and commissioning of the ASTERICS source might be long due to the state of the art design of this source, it is planned to proceed to these tests at the LPSC laboratory (Grenoble) by the source experts. Meanwhile, the transport lines of NEWGAIN and the RFQ will be tested at GANIL with the PHOENIX V3 beams.

Schedule

One of the most difficulties is to minimize the project interaction with the operation of the existing machine. SPIRAL2 has numerous operating periods and the schedule must take this major constraint (common to all existing installations) into account. The risk is that it will not be possible to take advantage of the machine downtime due to the unavailability of NEWGAIN equipment for installation. The project team must anticipate these periods in an agile manner. Thus, the first ongoing difficulty is the deep excavation, which requires descending to a depth of approximately 11 meters to create the emergency exit in the SPIRAL2 building. With authorizations from the technical controller running late, a six-month slippage has already impacted the project. The phases and order of equipment installation are then reorganized to meet the project milestones.

Figure 4 shows the project roadmap based on work packages.

INSTALLATION PROGRESS

Due to the short duration of the project, the strategy was to use as much as possible the design of the equipment already existing on SPIRAL2 to reduce the development study time by using as much as possible the design of the equipment already existing on SPIRAL2. Nevertheless, some equipment benefit from the SPIRAL2 experience feedback and implement necessary improvements.

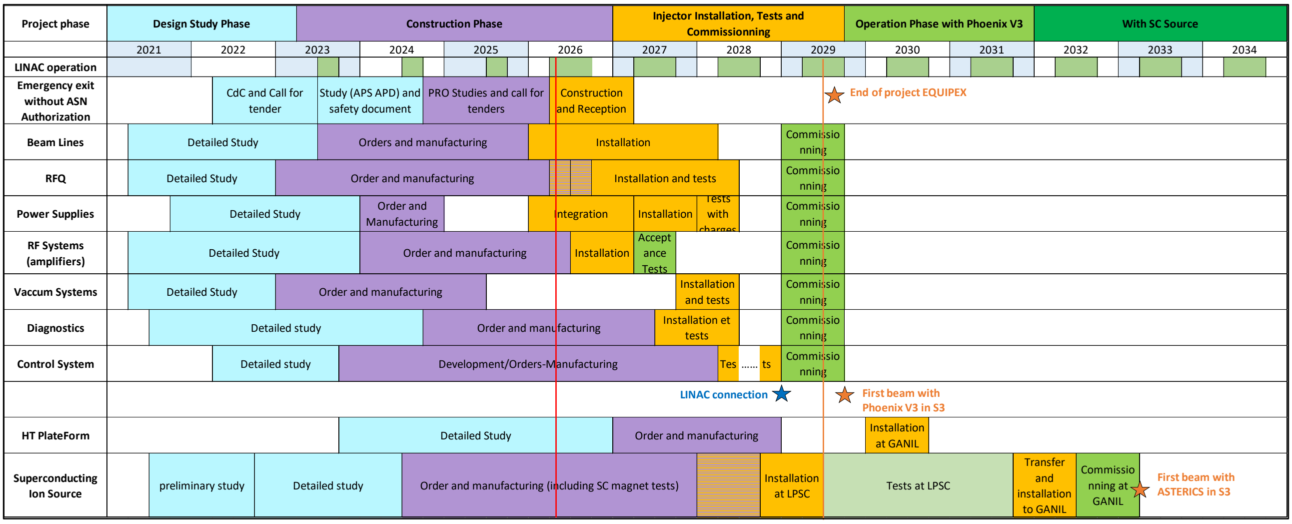

Figure 4: NEWGAIN roadmap.

The year 2025 (Fig. 4) marks the end of the main equipment order period. Vacuum equipment, power supplies and automatism devices have already been received and stored. The major equipment such as the RFQ, the ASTERICS superconducting coil, the quadrupoles, solenoids and RF amplifiers are still under construction.

Superconducting Ion Source

One of the main critical items of the source is its superconducting (SC) magnet constituted of one NbTi SC sextupole inside three NbTi SC solenoids. The preliminary design was first described in [2], and the detailed design of the magnet and its cryogenic satellite is in progress. The SC ion source is placed on a 50 kV platform. It was then decided to design an enlarged version of the VENUS ion source [3], called ASTERICS for Advanced Spiral Two Electron cyclotron Resonance Ion source at Caen with Superconducting magnet. The design [4] keeps a similar magnetic system as VENUS ion source but increases the overall plasma chamber dimensions: the cylindrical chamber has a 600 mm length (~500 mm for VENUS) and 181 mm diameter (141 mm for VENUS). The aim is to enhance significantly the magnetic intensity of the last closed magnetic surface (which mitigates the risk to burn the plasma chamber), and to provide space for the installation of dedicated hardware to enhance the conversion yield of metallic atoms into ion beam (new ovens, hot temperature controlled liners) [5]. The mechanical global view of the ion source is presented in Fig. 5.

In September 2024, the validation of the ground platform layout was completed. This step marked the convergence of a complex iterative process involving multiple conflicting constraints. In April 2025, the kick-off meeting for the ASTERICS superconducting magnet manufacturing contract took place. An international review of the source mechanics was held in May 2025. It allowed experts to evaluate both the source design and the construction strategies. The resulting report helped us to consolidate our implementation choices.

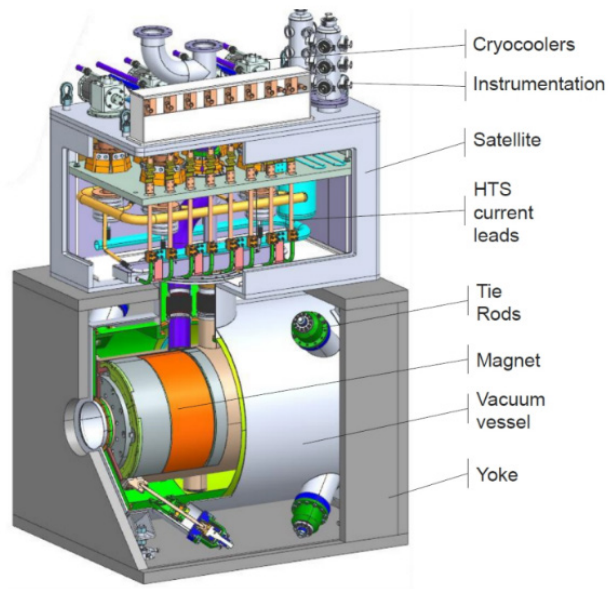

Figure 5: Skinned view of the ASTERICS cryostat ion source, its magnet and the surrounding iron yoke.

Beam Transport

The Low Energy Beam transport (LBE3-Fig. 6) connects the superconducting source to the RFQ. The possibility to use the beams from the existing Phoenix V3 source with higher mass-to-charge ratio than with the RFQ1 is added through a second dedicated low-energy transport (LBE13), connected to LBE3 upstream of the RFQ. The Medium Energy transport line (LME2) then injects the beam into the superconducting LINAC. The design has been optimized through beam dynamics calculation whose results are presented in [6].

The LBE3, whose optical functions are shown in Fig. 7, is composed of 2 solenoids after the ion source extraction, 2 sets of horizontal slits for A/q selection, an accelerating tube at the platform exit, 10 quadrupoles equipped with a vertical or horizontal steerer, two 90° dipoles, 6 profilers, 6 slits including 3 vertical and horizontal sets, 1 Pepper pot, 2 Faraday cups, one 20 kHz beam chopper, 1 Emittance meter in the 2 planes, 2 safety beam stops. 1 double solenoid at RFQ entrance and 1 AC-Current Transformer (ACCT) in flange.

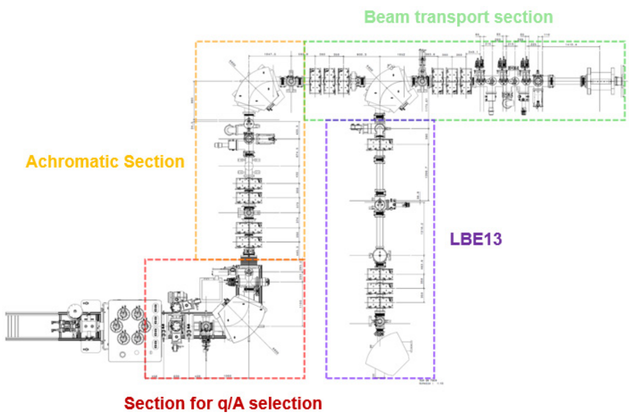

Figure 6: Optical functions of the LBE3.

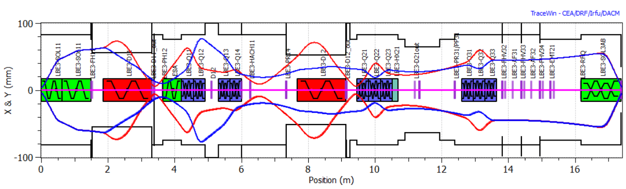

Figure 7: 3σ beam envelope for NEWGAIN up to the entrance of the RFQ1 of SPIRAL2.

The medium energy transport to the LINAC (LME2) is approximately 10 meters long and is composed of 4 triplets of quadrupoles including steering coils, 4 dipoles (3 identical and one insertion dipole in the LME1), 2 rebunchers, identical to those of SPIRAL2, 1 ACCT in flange at RFQ output, 1 Faraday cup, 5 profilers, 1 phase probe.

An additional section Low to Medium Energy Injection line (LMEI) is added at the 0° RFQ exit, towards a future experimental area. It already integrates a permanent "tuning" bench containing some diagnostics that could not be mechanically placed in the main MEBT. LMEI is composed of a triplet of quadrupoles, two phase probes, and a diagnostic chamber containing an emittance meter, a profiler, and fast and slow faraday cups.

The diagnostics enable the survey of the high intensity beam produced by the sources along the injector and extensive beam dynamics calculation have been done to first dimension the interceptive equipment such as Faraday cup, slits, dipoles, vacuum chambers. The various simulations help consolidate the mechanical design of the injector.

RFQ

The RFQ is a standard four-vane bulk copper cavity, composed of 7 segments. Mechanical studies are based on the first SPIRAL2 RFQ, for which the operational experience has been very positive [7]. The RF design was simplified by using a constant voltage profile and aimed at reducing the cavity loss to fit the surface available for the installation of the amplifiers, and to maintain the Kilpatrick factor below 1.65. The main RFQ parameters are presented in Table 3.

The RFQ cavity in Fig. 8 is composed of 7 sections and is currently under construction. The first two sections are currently being pre-assembled at the CEA/IRFU laboratory and all the other sections are expected to be delivered to GANIL from June 2026 to December 2026 [8].

Table 3: RFQ Main Parameters

Frequency	**88,0525**	**MHz**
Accelerating Voltage	70	kV
Surface Electric Field	1.65	Kilpatrick
Cavity loss	92	kW
Length	7	m
Vane Modulation	1 to 2.7	
Power coupling ports	4	
Tuners	56	

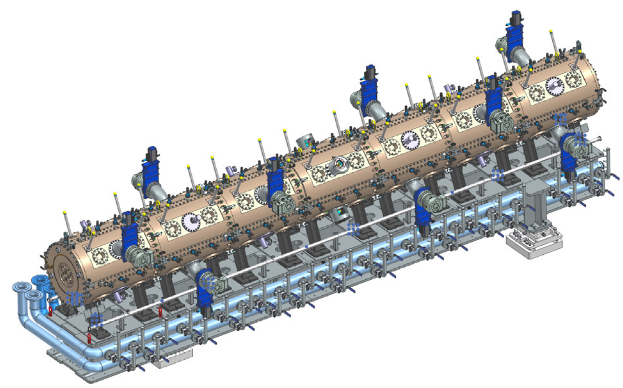

Figure 8: NEWGAIN RFQ2.

RF Systems

The RF systems for NEWGAIN is composed of rebunchers, amplifiers and transmission lines. It will be based on the LLRF designed for SPIRAL2 and on new solid-state amplifiers. The driving scheme for the 4-port RFQ will be simplified by using only one LLRF (instead of four in master/slave configuration) as shown in Fig. 9. Since the installation of the phase locked loop mode to turn on RFQ1, the reflected power to be managed has strongly decreased (< 12%) and the cost, dimensions and running constraints of circulators are probably no more justified. Then, the possibility of not using these devices has been investigated using a low-power 4-port resonant combiner. An isolated first splitter will be used, followed by gain and phase adjusters, to drive amplifiers equipped with in phase combiners, and transmission lines of equal phase length, to have similar working points of the transistors when the cavity is detuned. The first prototype of the base module, a 6 kW solid-state amplifier withstanding 15% mismatch, and containing 6 1.5 kW pallets), was produced by an industrial company and was successfully tested at the factory and at site. The series production has started the rebunchers amplifiers (1 and 10 kW) are expected in May, while the four 40 kW units for the RFQ should be delivered during the following months.

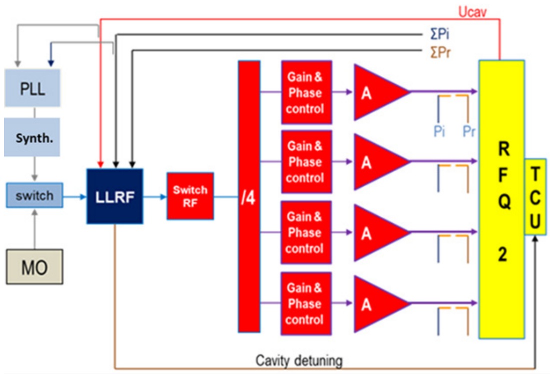

Figure 9: RFQ2 driving principle.

The 3D integration of the RF power distribution, including the option with circulators, was completed in May 2025. The call for tender was launched end of 2025 and the contract for equipment supply and installation was signed in February 2026. Installation is expected during next summer, but partial dismounting will be required to install the RFQ.

Diagnostics

Diagnostics that will be used for beam tuning and survey are identical to those installed on SPIRAL2 [9] except for the AC-Current Transformers (ACCT), placed at the RFQ entrance and exit. The modifications and developments primarily focus on sensitivity for low beam intensities. This work also concerns all SPIRAL2 diagnostics for future S3 beams. The current measurement range for the CF and ACCT is 1 mA to achieve sufficient accuracy for low intensities. The diagnostics pool will be composed of 4 Faraday cups, 15 profilers, 2 AC-Current Transformers, 3 phase probes, 2 emittance-meters. A new measurement system for phase probes is under development in collaboration with the French Laboratory LP2IB (project MENPHIESS). In addition, an upgrade of the existing SPIRAL2 beam survey systems has to be completed to take into account the new beams from NEWGAIN. The existing Timing system must be modified and upgraded in order to integrate NEWGAIN injector as well as the SPMT (Thermal Machine Protection System).

CONCLUSION

The construction phase of the NEWGAIN project started on May 2023 and is progressing well. In May 2025 the first symbolic modification of the existing SPIRAL2 line has been achieved, i.e. the installation of a new vacuum chamber in the common dipole LBE12 with a new exit to NEWGAIN. The next main milestones will be the deep excavation of the emergency exit in the existing building. This civil engineering operation is a prerequisite for any installation to establish the geodetic network of the room after construction. The main difficulty is the availability of technical human resources and a strict workload plan for the project but also for the entire GANIL projects is being consolidated to ensure the milestones are met. GANIL is a Basic Nuclear Installation (INB) and the project must request start-up authorization via safety files submitted to the French Nuclear Safety and Radiation Protection Authority (ASNR). 2029 should be the year of production of the first beams in NEWGAIN and see the first start-up of the ASTERICS superconducting source.

ACKNOWLEDGEMENTS

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